

Implementation of Wideband Digital Recording Equipment in the DSN

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The DSN is implementing wideband digital recording equipment for mission support in the 1978-1981 time era. This article describes the development status of this equipment and the factors which were of major importance in the design approach. Design of equipment is discussed to the functional block diagram level.

I. Introduction

Beginning in late 1977, wideband digital recording equipment will be implemented at the 64-meter Deep Space Stations (DSS). This equipment is necessary for support of flight project data acquisition and spacecraft navigation requirements. Specifically, a 12-megabit/sec recording capability is required in support of the Pioneer Venus probe entry wind experiment in December 1978; the capability to record 24 Mbits/sec is required for the DSN to use very long baseline interferometry (VLBI) techniques for determination of Earth platform parameters (UT-1 and polar motion) to the accuracy necessary for spacecraft navigation in the 1978-1981 time era.

Efforts toward implementing such a capability began in late 1974. Magnetic tape recording was adopted as the most acceptable means to accomplish digital recording at the required rates; multi-track recording on 2.5-cm (1-inch) wide magnetic tape, using an instrumentation-type

tape transport, is the general approach used by the recording industry to achieve such data rates.

II. System Design Factors and Influences

A. Capability Available From Commercial Sources

A key aspect of the implementation approach adopted by the DSN for wideband digital recording is to commercially procure *from a single contractor* that portion of the recording equipment which is to perform the primary functions of recording and reproducing user-supplied digital data at the rates and error tolerances required by the DSN. This approach places the responsibility for engineering those interfaces which are most critical to wideband digital recording in a single organization, and simplifies the specifications for the equipment being procured.

One of the first activities in the design effort was to become familiar with the capability that the recording

industry had achieved in wideband digital recording. The following summarizes the key observations made during this effort:

- (1) Several industry sources claimed digital recording capability in excess of 50 Mbits/sec.
- (2) There were (and are) no standards within the industry for wideband digital recording (i.e., formats, densities, track widths, track spacing, encoding system, etc.)
- (3) Although advertised as such, no truly "off-the-shelf" product line was offered by any industry source; this was in part due to the fact that users of such equipment had had widely varying requirements.
- (4) Most systems were still undergoing design changes and improvements.
- (5) There existed a large variance in the prices for equipment which ostensibly performed equivalent functions; in general the pricing of the equipment appeared high relative to the amount of electronics provided.
- (6) The specifications of system bit error rates were vague; specifically, techniques for distinguishing equipment errors from those errors resulting from tape imperfections were not well defined.

Following the industry survey, a JPL specification for 25-Mbit/sec recording equipment was generated. The technical requirements of this specification were written to be generally consistent with the level of capability observed during the industry survey; i.e., it was expected that several sources would be capable of supplying recording equipment in accordance with the JPL specification.

B. Supporting Research and Technology Activities

A second major influence on the implementation design approach was the related effort conducted by JPL's Communications Systems Research Section. In July 1974, a purchase order was issued by this section for the procurement of an off-the-shelf 80-Mbps record/reproduce system. The selected manufacturer encountered several difficulties in producing a system which met the required specifications. The specific technical outgrowths of this procurement which had an impact on the specification and selection of the DSN equipment were as follows:

- (1) A conservative design approach would preclude the use of tape track widths less than 25 mils for digital recording.

- (2) The procedures and techniques for testing bit error rates must be carefully specified to ensure that a truly *parallel* bit error rate is measured, and to eliminate the effects of tape flaws.
- (3) The minimization of electrical and mechanical adjustments is vital if the system is to be operationally acceptable.

C. Related Efforts Within NASA

Similar requirements for wideband digital recording exist within NASA for several planned and proposed applications. The rate requirements for these applications fall in the range of 15 to 120 Mbits/sec. Cognizance of these related efforts is under NASA's Goddard Space Flight Center (GSFC).

In March 1975, a JPL-GSFC wideband recorder technology working sub-group was established (as part of a larger VLBI working group); the primary objectives of this sub-group were to:

- (1) Exchange information as to development status and design approach.
- (2) Assess the degree to which format and interface standards could be adopted to permit inter-network experiments.
- (3) Assess the degree of operational risk associated with the relatively new level of technology present in wideband digital recording systems.

The first meeting of the working group was very productive in terms of information exchange, and there were several areas of agreement as to desirable interface and format characteristics. Although JPL had by this time selected a system contractor and the design of the equipment was well underway, several aspects of the detailed design were influenced by the results of this meeting. It is believed that the DSN equipment as currently designed could be readily compatible with any potential "NASA-standard" system.

D. Operational and Reliability Considerations

The most common reservations generally expressed about recording equipment center around operability, maintainability, and reliability. In an attempt to be responsive to these concerns, the following design goals were established and have been of major importance in the system design:

- (1) An automated pre-pass performance verification of the recording equipment should be provided.

- (2) Some degree of real-time read-after-write data monitoring capability should be provided.
- (3) Tape-changing should be the only real-time operator function; the functions of starting, stopping, and rewinding tape should be automated.
- (4) A hard-copy log of all recording activity should be provided.
- (5) The capability should be provided to receive control information from a remote operator, and to report system status to station monitoring equipment.
- (6) The recorder transport should accommodate 41-cm (16-inch) reels for extended recording time.
- (7) DSN Hi-Rel hardware should be used wherever appropriate.
- (8) The recording system MTBF should be >500 hr.
- (9) Modular design should be provided to facilitate troubleshooting and repair.
- (10) Mechanical and electrical adjustments should be minimized.

E. Cost Considerations

The effort to minimize costs while providing capability consistent with requirements has had an impact upon the design in two significant respects. The first was the procurement of the commercial recording equipment in two distinct configurations. One configuration is intended for use at DSSs, where data recording is the primary function, and the other is destined for use at a central playback facility. The "record" configuration has full 25-Mbit/sec recording capability but limited reproduce capability; the "reproduce" configuration has complete playback capability but only that record capability required for system performance checks. An estimated 20-percent reduction in price of the commercial recording equipment was achieved by procuring units without the full record/reproduce function.

Equipment costs were also minimized by implementing only 20 channels of electronics in recording equipment which is designed to accommodate 28 channels; the digital recording rates required for the DSN application can be comfortably accommodated on 20 recorded tracks. Although all systems are equipped with 28-track read/write heads and 28 channels of head drivers and reproduce amplifiers, those channel electronics which exhibit greater complexity and cost (record and reproduce amplifiers, encoders, and decoders) have been limited to the 20-channel configuration.

III. Detailed Design Description

A. Commercial Wideband Digital Recording Equipment

As outlined above, two configurations of recording equipment are being procured from a systems contractor. A functional block diagram of the record configuration is shown in Fig. 1. The input to the recording equipment consists of 20 synchronous channels of digital data and a common data clock. The nominal data rates per channel for the DSN configuration are shown in Table 1.

Each input channel is recorded on a separate track after being reformatted by the encode/sync-insertion logic. The reformatting process consists of merging additional data bits (on a non-replacement basis) with the input data for each channel. For every 200 user input bits received on a given channel, an additional 43 bits are generated and merged to create a 243-bit data frame. The frame content is shown in Fig. 2. As a result of the reformatting process, the actual bit rate of information recorded on each track is 21.5 percent higher than the original input bit rate. The primary functions of the reformatting are (1) to provide a means for removing skew between tracks during playback, (2) to limit the low-frequency content of the recorded serial bit stream, and (3) to provide a means for error detection during reproduction.

A limited read-after-write capability also exists in the record configuration. Two reproduce-decoder channels are provided; one of these channels is hardwired to a specific track, while the other can be switched via a multiplexer to any of the 20 recorded tracks. This multiplexing capability allows real-time monitoring of data quality on a track-selective basis. The functions of the decoder channels are (1) to eliminate data skew between recorded channels, (2) to remove the previously merged "overhead" bits and reproduce the data as it originally appeared at the user input, (3) to produce an error output signal which will indicate the bit error rate of the respective channel, and (4) to provide a signal which indicates the synchronization status of each decoder channel.

A block diagram of the reproduce configuration, intended for use at a central playback facility, is shown in Fig. 3. The individual elements of this configuration are equivalent in function to those of the record configuration. A full complement of reproduce amplifiers and decoders is provided for playback of 20 data tracks. The decoders and deskew electronics produce 20 synchronous channels of digital data. The content and phase relationship of these data is identical to that supplied by the user during the record process; the fact that overhead bits were added and

subsequently deleted during the record-reproduce process is transparent to the user.

An externally supplied data clock controls the data output frequency within a ± 2 -percent range of the nominal playback rates. Data can be reproduced at the originally recorded rate or at any of the nominal rates below the original rate.

B. Equipment Configuration at DSN Sites

A functional block diagram of the planned equipment configuration at DSN sites is shown in Fig. 4. The basic functional elements of the system are:

- (1) Analog-to-digital (A-D) converters and data formatter
- (2) Wideband recording equipment (2 units)
- (3) Recording monitor unit
- (4) Recording controller and log printer

The primary functions and characteristics of these elements are outlined below.

The A-D converters and data formatter will perform the following functions:

- (1) Digitize up to 6 analog inputs; single-bit quantization is planned for very long baseline interferometry (VLBI) applications, while 3-bit quantization of a single input will be provided for the Pioneer Venus wind experiment.
- (2) Derive A-D sampling clocks from the DSN hydrogen maser frequency reference; sampling rates up to 25 MHz can be provided with less than 3 nanoseconds sampling jitter.
- (3) Provide a utility input port which will allow any external digital data stream to be recorded.
- (4) Distribute the digitized data onto 18 parallel data lines for input to the recording equipment.
- (5) Generate two redundant channels of digital housekeeping data for input to the recording equipment. Housekeeping tracks will include data time tag, system configuration data, and auxiliary data received from the recording controller.
- (6) Provide a data generator which will serve as a data source for stand-alone performance evaluation of the equipment.

The functional characteristics of the "commercial recording equipment" shown in Fig. 4 were discussed in detail in Section IIIA. This equipment (transport and

electronics) will be controlled and monitored via a remote control interface connection to the recording controller.

The function at the recording monitor unit is to accumulate, display, and transmit to the controller data which reflects the status and condition of the recording process. Specific functional tasks performed are:

- (1) Selection of the multiplexed channel monitored during the read-after-write process.
- (2) Accumulation and display of statistics on the selected channel, and input of these statistics to the controller for verification of proper values.
- (3) Monitoring of the housekeeping tracks and extraction of the time tag information for display and verification of proper content by the controller.
- (4) Reflection of the status and activity of the tape transports.

It is planned for the recording controller, in conjunction with the log printer, to perform the following functions:

- (1) Stop, start, and sequence transports and rewind tapes when appropriate.
- (2) Monitor real-time data quality.
- (3) Receive auxiliary data (e.g., weather, radiometer, antenna position, etc.) through a DSN standard interface port and reformat these data for inclusion on the recorded housekeeping data tracks.
- (4) Detect system alarm conditions and transmit alarm status via the standard interface port.
- (5) Provide a hard-copy log of recording activity and performance characteristics.
- (6) Provide an automated pre-pass performance verification test.

IV. Installation Schedule

The current implementation schedule calls for installation and integration testing to be completed as indicated below:

DSS 14: 1 January 1978

DSS 43: 1 February 1978

Santiago (STDN station): 1 January 1978

Guam (STDN station): 1 February 1978

DSS 63: 1 March 1979

The equipment installed at Santiago and Guam is being loaned to the Spaceflight Tracking and Data Network (STDN) for support of the Pioneer Venus entry probe wind experiment and will be returned to the DSN in January 1979.

V. Potential for Expanded Recording Capability

An attempt has been made throughout the design process to provide a recording system which is general-purpose in nature, and to allow for future expansion or modification of recording capability. Some of the potential requirements for which such equipment could be used are:

- (1) Recording of digitized pre-detection telemetry data.
- (2) Recording of radio science data.
- (3) Post-detection recording of multi-megabit telemetry data streams.

Increases in recorded data rate capacity could be accommodated by any of the following means:

- (1) Recording data at a tape speed of 305 cm/sec (120 inches/sec), yielding an aggregate 55.6-Mbit/sec

capacity; recording time per reel, however, is reduced to 20 minutes at this tape speed.

- (2) Recording data at a tape speed of 610 cm/sec (240 inches/sec), yielding an 111-Mbit/sec capability. The operational feasibility of this tape speed is questionable, as reel changes are required at 10-minute intervals (assuming continuous recording on 41-cm (16-in.) reels). A second drawback is that the recording systems being supplied to the DSN will have no reproduce capability at 610 cm/sec. Data recorded at 610 cm/sec must be played back at 305 cm/sec.
- (3) Increasing the number of recorded tracks from 20 to 28. This would result in a 40% increase in capability at any tape speed.
- (4) Increasing on-tape bit density from the current 11 kbits/cm (28 kbits/inch) to 13 kbits/cm (33 kbits/inch).

All of the above are technically feasible, and there exists a potential system rate capability in the 150-Mbit/sec range. However, any future consideration of increasing the data rate capacity of the system must be heavily dependent on (1) the experience gained with the equipment in its present configuration, (2) operational considerations, and (3) equipment costs.

Table 1. Nominal DSN recording rates

Tape speed, cm/sec (in./s)	Input bit rate (per track), Mbits/sec	Aggregate bit rate (20 tracks), Mbits/sec
305 (120)	2.78	55.6
152 (60)	1.39	27.8
76 (30)	0.694	13.9
38 (15)	0.347	6.94

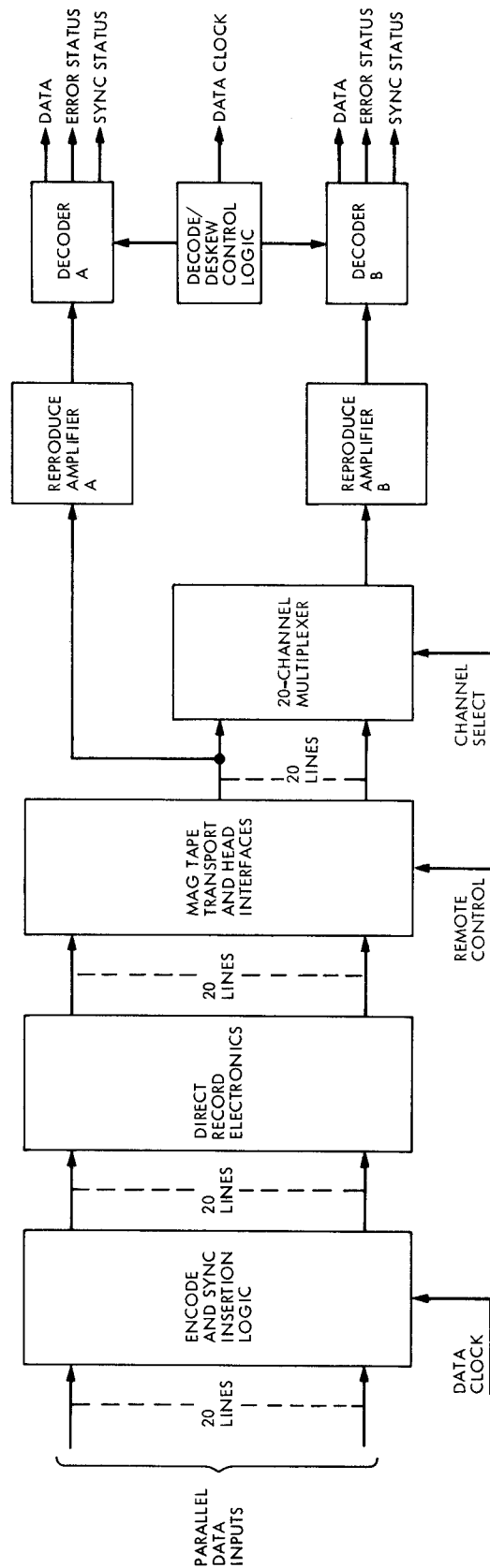
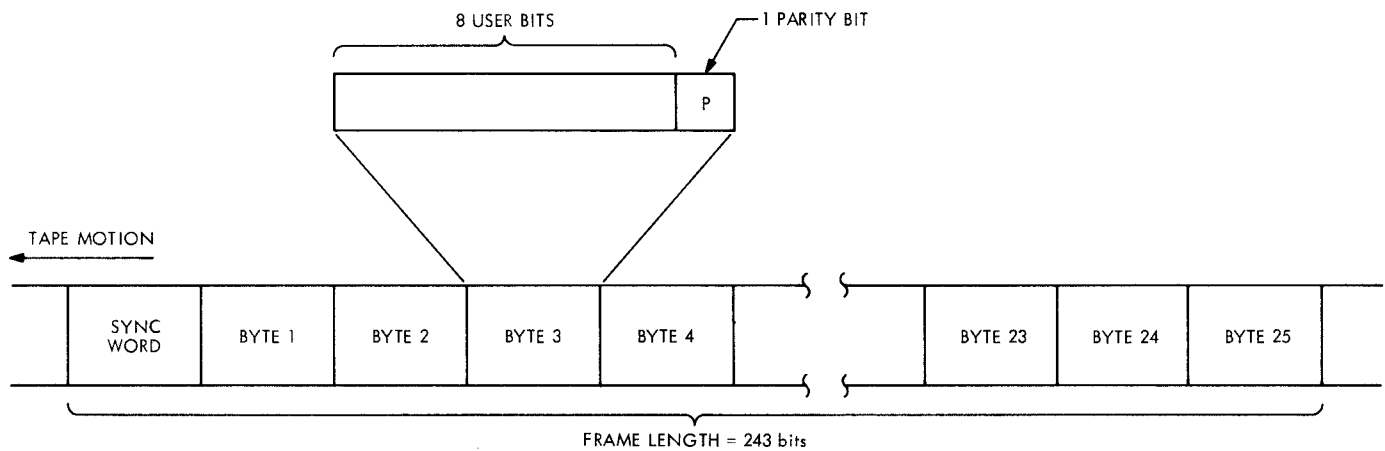


Fig. 1. Functional block diagram of commercial "record" configuration



FRAME CONTENT = 200 USER DATA INPUT BITS + 25 PARITY BITS + 18 SYNC BITS = 243 TOTAL
 SYNC WORDS = 746500_8 AND 031277_8 (ALTERNATING COMPLEMENTS)
 PARITY = ODD, CODING = NRZ-MARK
 OVERHEAD = 21.5%

Fig. 2. Recorded data format (typical for all tracks)

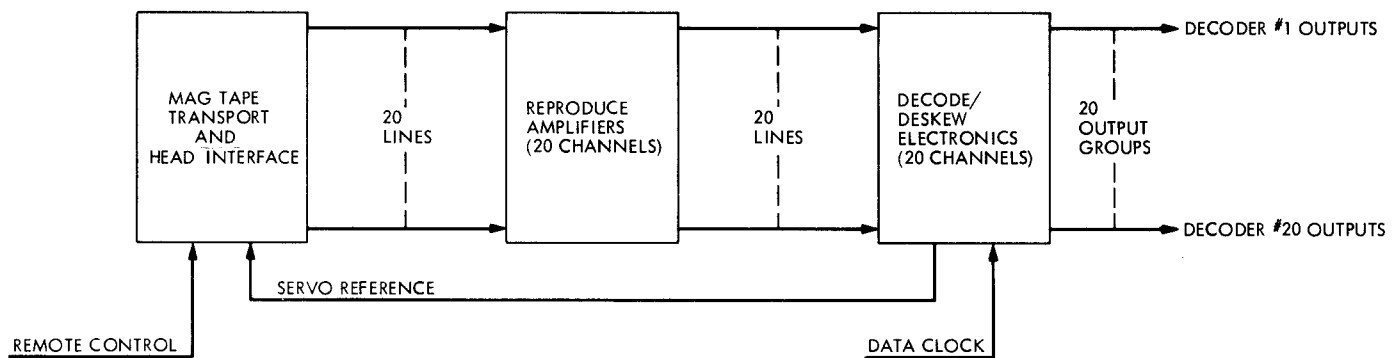


Fig. 3. Functional block diagram of commercial "reproduce" configuration

